Development of Narrow Wall Bracing and Effects of Boundary Conditions

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Summary

A significant amount of wood structural panel wall bracing tests have been completed in the development of new narrow wall bracing for use in the 2006 International Residential Code (IRC). In the development of new narrow wall bracing, testing was conducted on bracing segments that are currently permitted in the IRC to establish performance criteria from which to compare results. Testing has been completed on walls having various boundary conditions. Test results show that the braced wall segment strength and stiffness is highly dependent on the boundary conditions used. Some results of shear wall tests are also being examined. These results may be useful in the development of standards for evaluating wall bracing and for further developing wall bracing provisions in model codes.

1. Introduction and Background

Wall bracing is part of conventional light-frame construction provisions of the model codes to provide resistance to lateral loads from wind or earthquakes. Bracing serves the exact same function as shear walls except that instead of calculating a load and determining the shear wall strength required, the bracing requirements are prescribed, like a cookbook recipe, with few calculations and no engineering required. An implicit assumption is that if the prescribed wall bracing provisions are built as specified, then the structural performance will be adequate. The different types of bracing permitted (e.g. let-in, wood structural panel, gypsum, et al.) are recognized to perform differently as evidenced by the different prescribed limitations for each.

The 1970 edition of the Uniform Building Code (UBC) was the first occurrence of specific 48-inch minimum-width bracing panels, still seen in today's codes. In recent years, the codes have evolved to permit narrower than 48-inch-wide bracing segments in response to modern aesthetic demands. The 1994 UBC permitted 32-inch alternate braced-wall panels which prescribed sill plate anchorage and hold-down devices. The 2000 IRC permitted segments as narrow as 4:1 height-to-width ratio provided all exterior walls were continuously sheathed with wood structural panels and the clear opening height next to the 4:1 segment was limited to 0.65 times the wall height. The 2006 IRC now permits segments as narrow as 6:1 height-to-width ratio with certain specified limitations.

Most bracing segments in the IRC do not require the use of tie down devices, so the actual degree of end restraint the bracing segments will have is debatable. It is likely that some degree of end restraint is provided by additional wall length in which the bracing segment is used, use of additional structural sheathing elsewhere along the wall, perpendicular walls, finishes, the three dimensional shell and/or dead loads. Some argue [1] that since high winds can cause uplift, counting on the structure to provide restraint to an individual segment is unconservative or incorrect.

Historically, end restraint has been used or assumed in the testing and development of wall bracing intended to be used for conventional construction. Trayer [2] tested the racking strength and stiffness of several commonly used, at the time, wall bracing methods and used a hold-down rod, very similar to that specified in ASTM E 72. Toumi and Gromala [3] tested the racking strength of walls with let-in corner bracing and sheet materials in accordance with ASTM E 72 with its hold-down rod. Today, the ICC Evaluation Service [4] Acceptance Criteria 269, for evaluating proprietary wall bracing for use in the IRC requires ASTM E 72, which uses a hold-down rod, or ASTM E 564, which uses hold-down devices. In the development of the IRC [5] the 317 plf allowable design unit shear values assigned to the Method 3 (wood structural panel) bracing correspond to values only attained for similar shear walls with a high degree of end restraint.

Justification for assuming that some degree of end restraint will be present on braced wall segments can be found in test results and the historical performance record. Testing by the NAHB Research Center [6] and Dolan and Heine [7] of walls with 2-ft and 4-ft return corners showed that such corners provide end restraint to a wall similar to that of wall with a hold down; however, there is some speculation that orthogonal loading at the corners may not yield the same results [8]. Testing by Ni and Karacabeyli [9] showed that as walls become longer they approach the performance of a wall with end stud uplift restraint. Shake table testing shows that a small house having perforated shear walls with hold downs in the corners performed very similar to the same house constructed conventionally, with no hold downs; however, tests comparing segmented shear walls with hold downs on each segment had less drift than the conventional house with no hold downs [10]. Whole house testing done in Australia [11] showed that the conventionally constructed walls have strength and stiffness values on the order of similar wall segments tested with end restraint. Historically, houses constructed in accordance with the prescriptive bracing requirements have not had bracing failures.

This paper presents test results for a wall detail tested with different boundary conditions at the top, bottom and ends of the wall.

2. Description of Bracing Tests

During the development of new narrow wall bracing, testing was conducted on bracing segments that are currently permitted in the IRC to establish performance criteria from which to compare results. Figure 1 shows the 4:1 height-to-width ratio bracing segment wall tested, which is currently permitted per IRC Section R602.10.5. Figure 2 shows the framing details for the tests conducted on a raised wood floor assembly.

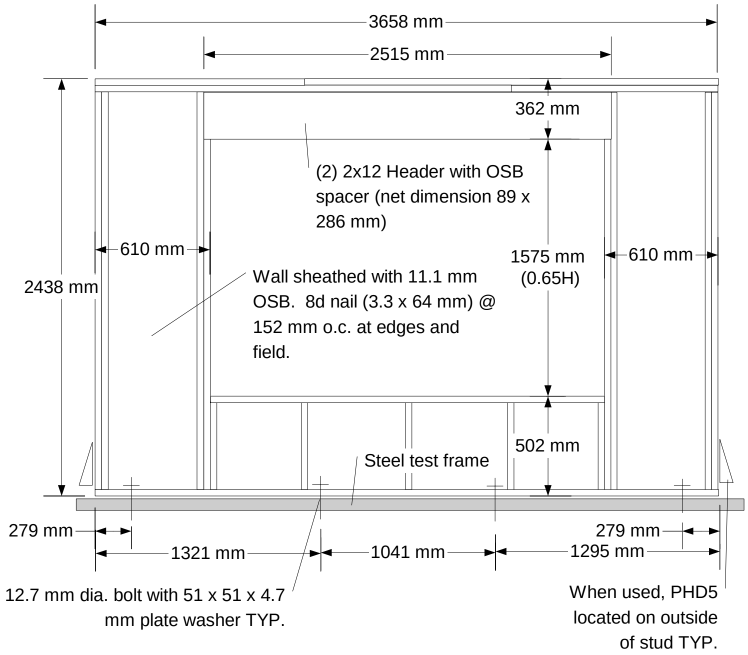

Figure 1. Framing detail of the basic 4:1 height-to-width ratio wall tested. (Note that not all tests had end post hold downs nor bottom plate bolts.)

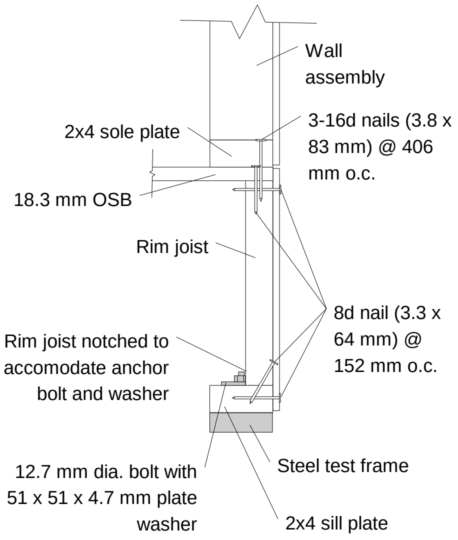

Figure 2. Framing detail of the raised wood floor assembly on which walls were attached and tested.

The different boundary conditions used for each of the wall bracing tests are summarized in Table 1. Two of the walls, C and G, were tested on a raised wood floor assembly as shown in Figure 2. Further details of the raised wood floor bracing tests have been published [12,13]. Other walls were tested on a steel channel foundation.

The nut tightness of 13.3 kN approximately corresponds to the tension measured in a 12.7 mm diameter bolt when the nut is tightened onto the specified 51 mm washer on a Hem-fir pressure treated sill plate with an air impact wrench. A nut tightness of 2.2 kN approximately corresponds to the bolt tension measured when the nut is tightened finger tight plus ¼ turn.

Gypsum, 12.7 mm thick, was used on the backside of walls B, E and F and was cut around the openings so that it was continuous around openings. The gypsum was not taped nor mudded. The

OSB sheathing was not cut around openings so that pieces were discontinuous around the openings. Further details of the testing done with gypsum are available from APA [14].

End of wall restraints (hold downs) were used on some tests to represent a case of high degree of end restraint and further descriptions have been published [12,15].

At the top of the wall, load was applied through either a stiff beam or USP TD15 hold down device attached to the double top plate of the wall. Most tests had a stiff beam, which has a bending stiffness (EI) of approximately 7.17 x 10^9 kN-mm^2 and a weight of about 227 kg. Test F used a USP TD15 hold down device that added no additional stiffness to the top plate of the walls.

Table 1. Boundary conditions used in bracing tests

Test	Wall Tested On	Bottom Plate Attachment	Nut Tightness[1] (kN)	Backside of Wall[2]	End of Wall Restraint	Top of Wall[3]
A	Steel Frame	Bolt and Washer	13.3	Bare	PHD5	Stiff Beam
B	Steel Frame	Bolt and Washer	2.2	Gypsum	PHD5	Stiff Beam
C	Raised Wood Floor	Nails per IRC	--	Bare	PHD5	Stiff Beam
D	Steel Frame	Bolt and Washer	13.3	Bare	None	Stiff Beam
E	Steel Frame	Bolt and Washer	2.2	Gypsum	None	Stiff Beam
F	Steel Frame	Bolt and Washer	2.2	Gypsum	None	USP TD15
G	Raised Wood Floor	Nails per IRC	--	Bare	None	Stiff Beam

1. Nut tightness refers to nuts placed on bolts and washers and hold downs (when used).
2. Gypsum fastened with #6 x 41 mm drywall screws every 406 mm o.c.
3. Device used to impart lateral load into wall attached to double top plate of test wall.

Walls were tested cyclically following the sequential phased displacement (SPD) method, as outlined in SEAOSC [16]. The first major event (FME), for use in the SPD test method, was set at 30.5 mm based on previous test results.

3. Bracing Test Results

Test results show that the braced wall segment strength and stiffness is highly dependent on the boundary conditions. Figure 3 provides a summary of the backbone curve test results. The curves in Figure 3 represent the absolute average values of the positive and negative displacement excursions from the backbone curves. For the different boundary conditions tested, the general response curves show that:

- The ultimate load capacity varies by a factor near 2, and
- The displacement at a given load can vary by a factor of around 6.

These observed differences are very significant. Each boundary condition could arguably be representative of actual boundary conditions. In fact, actual boundary conditions may be even more varied than these tested considering the possible dead loads acting on the wall, which would likely improve performance as observed by Dean and Shenton [17], or net uplift on the wall which may actually decrease performance.

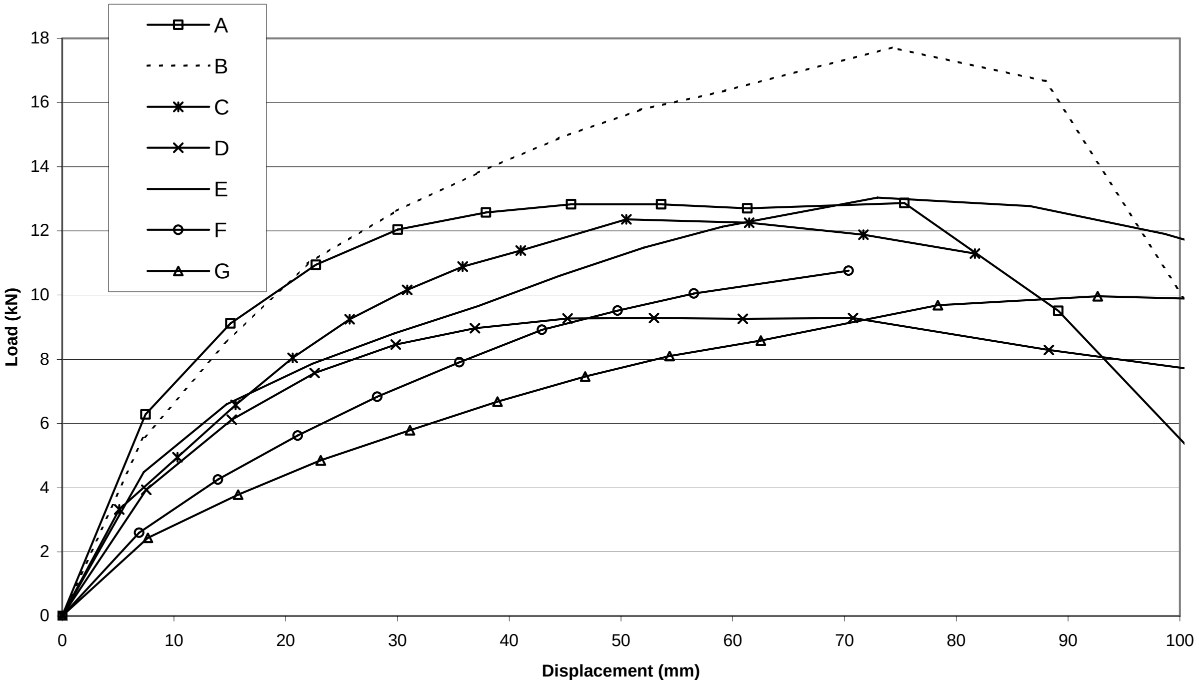

Figure 3. Summary backbone curves from the bracing tests.

4. A Brief Look at High Capacity Shear Walls and Boundary Conditions

While it is logical that low capacity prescriptive narrow wall bracing which do not require the use of hold down devices would be very sensitive to different boundary conditions, even high capacity shear walls are affected by bottom of wall and top of wall boundary conditions. Shear walls 1 and 2 were both constructed exactly the same, with 11.1 mm OSB sheathing on both sides of the framing with 8d cooler nails (2.9 mm x 60 mm) spaced 51 mm o.c. at the panel edges. Both of the walls used the exact same hold down device. Table 2 summarizes the boundary conditions for shear walls 1 and 2. Figures 4 and 5 show the details of the “Z” and “C” sections, respectively, on which the shear walls were tested.

Figure 6 provides a summary of the backbone curve test results for shear walls 1 and 2. The curves in Figure 6 represent the absolute average values of the positive and negative displacement excursions from the backbone curves.

Table 2. Boundary conditions used in shear wall tests

Test	Wall Tested On	Bottom Plate Attachment	Nut Tightness[1] (kN)	Top of Wall Load Beam[2] Type	Top of Wall Load Beam[2] Stiffness kN-mm^2
1	Steel "Z" Section	Bolt and Washer	13.3	Built-up Steel Beam	7.17 x 10^9
2	Steel "C" Section	Bolt and Washer	2.2	Steel Channel C5x9	5.25 x 10^7

1. Nut tightness refers to nuts placed on bolts and washers and hold downs.
2. Device used to impart lateral load into wall attached to double top plate of test wall. Neither type restrained wall sheathing.

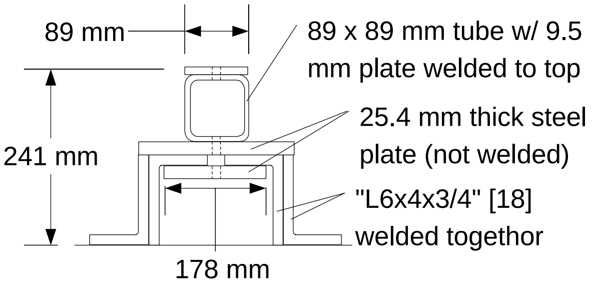

Figure 4. Steel "Z" section used as the base for shear wall tests. The section is bolted to tubes, which are bolted to a concrete floor.

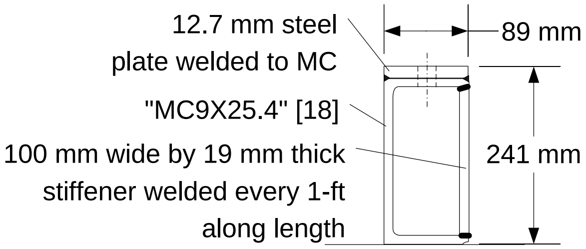

Figure 5. Steel "C" section used as the base for shear wall tests. The section is bolted to tubes, which are bolted to a concrete floor.

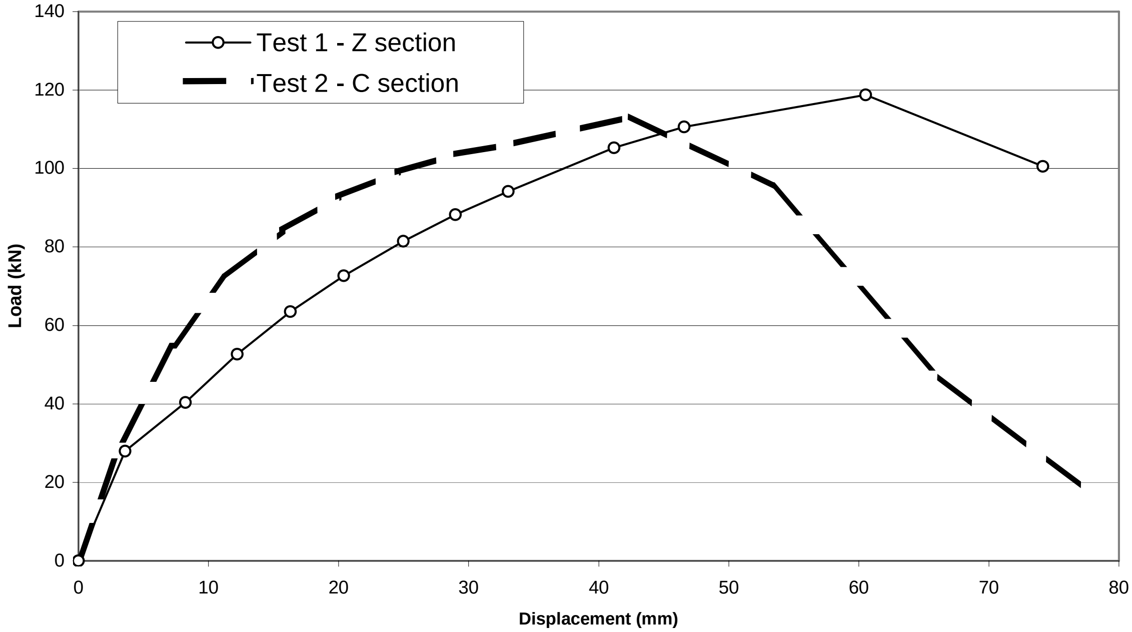

Figure 6. Summary backbone curves from the shear wall tests.

The shear wall test results show that:

- The stiffness, more than peak load capacity, is affected by the bottom of wall and top of wall boundary conditions.
- The bottom of wall boundary conditions may be more influential then nut tightness or top wall load beam stiffness.

The test results suggest that if shear wall stiffness is an important performance parameter, documentation of all test boundary conditions is essential to facilitate the comparison of test results between test laboratories.

5. Discussion and Conclusion

This paper presents results of cyclic racking shear tests on wall segments having different boundary conditions. The test results show that the observed performance, particularly initial stiffness, in the range of 12 mm displacement, is highly dependent on wall boundary conditions. For wall bracing, differences in stiffness due to different boundary conditions can be on the order of 500% or more. As stiffness becomes a more important characteristic for design and/or design value derivation, the appropriate boundary conditions become more important. For wall bracing which does not require the use of hold down devices, the issue is even more complex as the potential restraint provided by the structure is variable, relatively unknown, and unquantified.

Work is underway to determine what boundary conditions are most appropriate for wall bracing. ASTM E 2126 is being modified to further standardize boundary conditions for wall bracing tests. The test results presented in this paper may be useful in the development of standards for evaluating wall bracing and for further developing wall bracing provisions in model codes.

6. References

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